Biomechanical Analysis of Pullout Strengths of Rotator Cuff and Glenoid Anchors: 2011 Update

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Purpose: To evaluate the biomechanical and design characteristics of newer suture anchors. **Methods:** Suture anchors were tested in fresh porcine metaphyseal cortex and cancellous troughs by use of an established protocol. A mechanical testing machine applied tensile loads parallel to the axis of insertion at 12.5 mm/s until failure, and mean anchor failure strengths were calculated. The mode of failure was recorded. Rotator cuff anchors tested included the Doubleplay and Opus SpeedScrew (ArthroCare Sports Medicine, Sunnyvale, CA); PEEK Intraline and PEEK Zip (Stryker, San Jose, CA); Paladin, SuperRevo FT, and CrossFT (ConMed Linvatec, Largo, FL); Piton (Tornier, Warsaw, IN); Ti Screw, ALLthread PEEK, LactoScrew, ALLthread Ti, and ALLthread PEEK knotless (Biomet Sports Medicine, Warsaw, IN). Glenoid anchors included the Gryphon BR P (DePuy-Mitek, Raynham, MA) and JuggerKnot 1.4 (Biomet Sports Medicine). **Results:** Mean cortical failure loads for cuff anchors were as follows: Doubleplay 5.0, 279 N; Doubleplay 6.5, 338 N; Opus SpeedScrew 5.5, 356 N; Opus SpeedScrew 6.5, 336 N; PEEK Intraline 5.5, 263 N; PEEK Intraline 6.5, 344 N; PEEK Zip 5.5, 435 N; PEEK Zip 6.5, 502 N; Paladin 5.0, 500 N; Paladin 6.5, 521 N; SuperRevo FT, 496 N; CrossFT, 569 N; Piton, 379 N; Ti Screw 5.0, 457 N; Ti Screw 6.5, 443 N; ALLthread PEEK 5.5, 476 N; LactoScrew 5.5, 403 N; ALLthread Ti 5.0, 526 N; ALLthread Ti 6.5, 653 N; and ALLthread PEEK knotless, 441 N). Mean cortical failure loads for glenoid anchors were 161 N for Gryphon BR P and 239 N for JuggerKnot 1.4. Mean cancellous bone failure loads for cuff anchors were Doubleplay 5.0, 263 N; Doubleplay 6.5, 340 N; Opus SpeedScrew 5.5, 356 N; Opus SpeedScrew 6.5, 344 N; PEEK Intraline 5.5, 274 N; PEEK Intraline 6.5, 327 N; PEEK Zip 5.5, 401 N; PEEK Zip 6.5, 396 N; Paladin 5.0, 427 N; Paladin 6.5, 491 N; SuperRevo FT, 483 N; CrossFT, 547 N; Piton, 365 N; Ti Screw 5.0, 420 N; Ti Screw 6.5, 448 N; ALLthread PEEK 5.5, 475 N; LactoScrew 5.5, 435 N; ALLthread Ti 5.0, 512 N; ALLthread Ti 6.5, 612 N; and ALLthread PEEK knotless, 466 N). Mean cancellous failure loads for glenoid anchors were 117 N for Gryphon BR P and 194 N for JuggerKnot 1.4. None of the anchors had pullout as the predominant failure mode. Eyelet failure was the predominant failure mode for Doubleplay, Opus SpeedScrew, PEEK Intraline, Gryphon BR P, ALLthread Ti 6.5, ALLthread PEEK 5.5, and LactoScrew. **Conclusions:** Failure load was not dependent on anchor location (cancellous or cortical bone) ($P = .58$) but was dependent on anchor type (cuff anchor or glenoid anchor) ($P < .001$). **Clinical Relevance:** Whereas larger fully threaded screw anchors designed for rotator cuff repair showed higher failure strengths than smaller non-screw anchors designed for glenoid repairs ($P < .05$), the larger version of a screw anchor for a cuff repair did not provide a statistically greater failure load than the smaller screw anchor.

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New suture anchor designs continue to appear for use with arthroscopic techniques. Most recently released anchors are designed to facilitate rotator cuff repairs, whereas others address biceps tenodesis and glenohumeral use.[1-8] Recent innovations in anchor design and application include the use of polyetheretherketone (PEEK) as the anchor material,[9] the addition of multiple high-strength sutures, the development of "knotless" designs that may be used for the lateral row of a dual-row rotator cuff technique,[2,3,10,11] and the application of anchors to hip labral repair.[12] PEEK is a radiolucent but not biodegradable plastic suitable for a variety of implants that has the advantages of being high strength, enabling good postoperative imaging, and facilitating revision surgery because it is soft enough to be drilled through. High-strength sutures[13] made in part or entirely with ultrahigh–molecular weight polyethylene (UHMWPE) have implications for the associated anchors because the increased suture strength places greater demands on the suture-anchor fixation point ("eyelet") at loads associated with failure that are unique to that design. Anchor designs that do not require an arthroscopically tied knot ("knotless") facilitate secure repair fixation but have technique and mode-of-failure implications.[14,15]

Other recent trends in anchor development include the increased use of biodegradable materials.[16,17] As suture anchor technology develops, older anchors and techniques are replaced with newer ones.[18] An understanding of the failure mode and strength characteristics of these new devices is necessary for the surgeon considering their use. The purpose of this study is to evaluate the biomechanical and design characteristics of newer suture anchors. Our hypothesis is that newer suture anchors have different failure profiles reflecting changes in anchor design and the anatomic location of anchor use.

METHODS

The rotator cuff anchors tested included the Doubleplay 5.0 and 6.5 and Opus SpeedScrew (ArthroCare Sports Medicine, Sunnyvale, CA); PEEK Intraline 5.5 and 6.5 and PEEK Zip 5.5 and 6.5 (Stryker, San Jose, CA); Paladin 5.0 and 6.5, SuperRevo FT, and CrossFT (ConMed Linvatec, Largo, FL); Piton (Tornier, Warsaw, IN); and ALLthread Ti 5.0 and 6.5, ALLthread PEEK 5.5, LactoScrew 5.5, Ti Screw 5.0 and 6.5, and ALLthread PEEK knotless (Biomet Sports Medicine, Warsaw, IN). The glenoid anchors tested included the Gryphon BR P (DePuy-Mitek, Raynham, MA) and the JuggerKnot 1.4 anchor (Biomet Sports Medicine). Anchor material, size, suture number type and material, anchor major and minor diameters, and anchor lengths are included in Table 1.

Cuff Anchors

The Doubleplay anchors (Fig 1) are manufactured from a resorbable composite of 30% β tricalcium phosphate (β-TCP)/70% poly-L-lactic acid (PLLA). They have an eyeless design with full-length threads to engage both cortical and cancellous bone, as well as a hollow core. Both 5-mm and 6.5-mm implants were tested. These anchors are supplied with a UHMWPE braided suture (MagnaForce; ArthroCare Sports Medicine) that runs up through the hollow body and doubles back around the outside of the implant to lie securely within 2 shallow grooves that lie the length of either side of the implant. Once inserted, these grooves allow the sutures to slide freely for knot tying.

The Opus SpeedScrew 5.5 and 6.5 knotless implants (Fig 1) are made from PEEK. This screw-in knotless anchor can hold several sutures and locks them within the implant rather than against the adjacent bone as with other knotless anchors.

PEEK Intraline 5.5 and 6.5 anchors (Fig 2) are made from PEEK and contain 2 No. 2 Force Fiber sutures (Stryker) (braided UHMWPE). Each is a fully threaded screw-in anchor with an internal suture eyelet also made of Force Fiber within the body of the screw. The insertion hole may be prepared with a punch and a tap.

PEEK Zip 5.5 and 6.5 are PEEK screw anchors (Fig 2) also containing 2 No. 2 Force Fiber sutures (braided UHMWPE) threaded through 2 independent eyelet tracks in the screw head. This anchor is fully cannulated with a trocar-tip inserter that distributes the insertion torque along the entire implant length. The anchor has an unobstructed central lumen that may provide a channel for marrow elements to reach the soft tissue once the inserter is removed.

SuperRevo FT (Fig 3) is a metal, fully threaded, self-drilling screw anchor made of titanium with an internal independent suture-sliding eyelet. The SuperRevo FT is pre-threaded with 2 No. 2 Hi-Fi sutures (ConMed Linvatec) and is designed for cortical fixation.

The Paladin is a screw anchor (Fig 3) available in 5.0- and 6.5-mm diameters manufactured from self-reinforced 96% L/4% D poly lactic acid (SR-PL96D4LA). The core diameter tapers distally and matches the self-drilling tap used for insertion. This blue anchor is double loaded with 2 No. 2 Hi-Fi

TABLE 1. *Suture Anchor Properties*

Anchor	Material	Suture	Loaded	Minor	Major	Length	Other Information
Cuff anchors							
Doubleplay 5.0	30% β-TCP/70% PLLA	No. 2 MagnaForce	Double		5.0 mm	12 mm	Hollow body, grooves on outside
Doubleplay 6.5	30% β-TCP/70% PLLA	No. 2 MagnaForce	Double		6.5 mm	12 mm	Hollow body, grooves on outside
Opus 5.5 SpeedScrew	PEEK	Any	2 or more	3.7 mm	5.5 mm	16 mm	Knotless, lateral-row anchor
Opus 6.5 SpeedScrew	PEEK	Any	2 or more	3.7 mm	6.5 mm	16 mm	Knotless, lateral-row anchor
PEEK Intraline 5.5	PEEK	No. 2 Force Fiber	Double	3.0 mm	5.5 mm	13.5 mm	Separate proximal suture eyelets
PEEK Intraline 6.5	PEEK	No. 2 Force Fiber	Double	3.0 mm	6.5 mm	13.5 mm	Separate proximal suture eyelets
PEEK Zip 5.5	PEEK	No. 2 Force Fiber	Double	2.7 mm	5.5 mm	17 mm	
PEEK Zip 6.5	PEEK	No. 2 Force Fiber	Double	3.3 mm	6.5 mm	17 mm	
Paladin 5.0	SR-PL96D4LA	No. 2 Hi-Fi	Double	3.52 mm tapered	5.0 mm	15.25 mm	Self-reinforced polymer
Paladin 6.5	SR-PL96D4LA	No. 2 Hi-Fi	Double	4.06 mm tapered	6.5 mm	16.25 mm	Self-reinforced polymer
SuperRevo FT	Titanium	No. 2 Hi-Fi	Double	Tapered core	5.0 mm	17 mm	Independent suture-sliding eyelet
CrossFT	PEEK	No. 2 Hi-Fi	Triple	3.8 mm	5.5 mm	17 mm	
Piton	Nitinol/Ti	No. 2 Force Fiber	2 suture limbs	3.5 mm	8 mm deployed	13 mm	Knotless lateral row, independent suture tensioning
ALLthread Ti 5.0	Titanium	No. 2 MaxBraid	Double	3.2 mm	5.0 mm	17 mm	Fully threaded screw anchor
ALLthread Ti 6.5	Titanium	No. 2 MaxBraid	Double	3.2 mm	6.5 mm	17 mm	Fully threaded screw anchor
ALLthread PEEK Triple 5.5	PEEK	No. 2 MaxBraid	Triple	3.5 mm	5.7 mm	15.8 mm	Fully threaded screw anchor
ALLthread PEEK Knotless 5.5	PEEK	No. 2 MaxBraid	Multiple limbs	3.6 mm	5.7 mm	14.7 mm	Knotless anchor
LactoScrew 5.5	85%/15% PLLA/PGA	No. 2 MaxBraid	Double	2.8 mm	5.8 mm	16.2 mm	
Ti-Screw 5.0	Titanium	No. 2 MaxBraid	Double	1.3 mm	5.1 mm	15.3 mm	
Ti-Screw 6.5	Titanium	No. 2 MaxBraid	Double	1.5 mm	6.6 mm	15.3 mm	
Glenoid anchors							
Gryphon BR P	30% β-TCP/70% PLGA	No. 2 Orthocord	Double	2.5 mm	3.0 mm	10.7 mm	Impaction anchor (push in)
JuggerKnot 1.4	Polyester	No. 1 MaxBraid	Single	1.4 mm		10.2 mm	Anchor made totally from suture

Abbreviations: SR-PL96D4LA, self-reinforced 96% L/4% D poly lactic acid; PEEK, polyetheretherketone; FT, fully threaded; Ti, titanium; PGA, polyglycolic acid; PLGA, poly levo-co-glycolic acid.

sutures (braided UHMWPE) through a single eyelet located at the first screw thread below the anchor top.

The CrossFT is a 5.5-mm-diameter PEEK screw anchor (Fig 3) with a distal crossbar eyelet that accommodates up to 3 No. 2 Hi-Fi sutures. There is a single screw thread that extends from the proximal anchor to the distal end and a second interleaved thread placed at the proximal end to maximize cortical compression.

The Piton anchor (Fig 3) is a 3.5-mm-diameter, knotless, direct insertion (no drilling) implant made from nitinol (50% titanium/50% nickel) and titanium. Two No. 2 Force Fiber sutures (UHMWPE) are provided with the anchor. As the anchor deploys, the tines

FIGURE 1. From left to right are the Doubleplay 5.0 and 6.5 anchors (ArthroCare Sports Medicine) and Opus SpeedScrew 5.5 and 6.5 knotless implants (ArthroCare Sports Medicine). The Doubleplay anchors are manufactured from an absorbable composite of 30% β-TCP/70% PLLA. The eyeless design has a hollow core, and braided sutures pass through the hollow body and double back around the outside of the implant to lie securely within 2 shallow grooves. The Opus SpeedScrew is made from PEEK with a distal crossbar eyelet. © 2011 F. Alan Barber.

expand to provide subcortical anchor fixation. The sutures can be independently and sequentially tensioned by the inserter.

The Ti Screw 5.0 and 6.5 anchors (Fig 4) have a deep cancellous thread with a small solid core diameter (1.3 to 1.5 mm) and are made from titanium.

FIGURE 2. From left to right are the PEEK Intraline 5.5 and 6.5 anchors and PEEK Zip 5.5 and 6.5 anchors (Stryker). These nonabsorbable PEEK anchors each contain 2 No. 2 high-strength sutures. © 2011 F. Alan Barber.

FIGURE 3. From left to right are the Gryphon BR P anchor (DePuy-Mitek) with 7 ribs composed of 30% β-TCP/70% poly levo-co-glycolic acid (PLGA), the fully threaded SuperRevo FT titanium anchor (ConMed Linvatec), the biodegradable Paladin screw anchor composed of self-reinforced 96% L/4% D poly lactic acid, the PEEK CrossFT anchor (ConMed Linvatec) with a distal crossbar eyelet and a double interleaved thread pattern, and the nitinol and titanium Piton anchor (Tornier), with its 4 tines deployed. © 2011 F. Alan Barber.

These anchors possess a conventional screw hub eyelet that is double loaded with 2 No. 2 MaxBraid sutures.

The ALLthread PEEK 5.5 anchor (Fig 4) (also available in a 6.8-mm size) is fully threaded with dual independent internal eyelets and comes double loaded with MaxBraid suture. The core is not tapered like the titanium version of this anchor.

The LactoScrew anchor (Fig 4) tested is 5.5 mm in diameter (also available in a 6.8-mm size) with dual independent eyelets to accommodate 2 No. 2 MaxBraid sutures. It is fully threaded for cortical bone purchase and composed of 85% PLLA and 15% polyglycolic acid material.

The ALLthread Ti 5.0 and 6.5 screw anchors (Fig 4) are fully threaded for cortical bone purchase and made from titanium. These anchors have a taped core with a sharp tip and dual independent internal eyelets, and they come double or triple loaded with braided UHMWPE MaxBraid sutures (Biomet Sports Medicine).

The ALLthread PEEK knotless anchor (Fig 4) is 5.5 mm in diameter but without the sharp tip of the ALLthread PEEK anchor. The hollow core extends the entire length of the anchor and permits sutures to pass completely through it to achieve the knotless fixation.

Glenoid Anchors

Gryphon BR P is a push-in anchor (Fig 3) with 7 ribs composed of 30% β-TCP/70% poly levo-co-glycolic acid and comes with 1 or 2 No. 2 Orthocord sutures

FIGURE 4. From left to right are the Ti Screw 5.0 and 6.5 anchors, the ALLthread PEEK 5.5 anchor, the LactoScrew anchor, the ALLthread Ti 5.0 and 6.5 screw anchors, the JuggerKnot 1.4 anchor, and the ALLthread PEEK knotless anchor (Biomet Sports Medicine). © 2011 F. Alan Barber.

(UHMWPE and polydioxanone) (DePuy-Mitek). The sutures pass down a central hollow core in the anchor and loop around a distal crossbar eyelet.

The JuggerKnot 1.4 anchor (Fig 4) is composed entirely of suture. The single No. 1 MaxBraid suture passes through a sleeve of braided polyester suture in a "V" configuration, which provides the anchoring mechanism when deployed.

Testing Protocol

Commercially available suture anchors were obtained from the manufacturers for testing. Fresh porcine femurs were obtained from a local abattoir. The pigs were aged 3 to 4 years and weighed between 200 and 300 kg at the time of slaughter. The femurs were stripped of all soft tissue and 2 different areas of insertion defined: the distal metaphyseal cortex and a cancellous trough created by decortication with an electrically powered bur in the distal femoral metaphysis. At least 10 samples of each anchor to be tested were obtained. All anchors were provided with high-strength UHMWPE-containing sutures and tested with these sutures.

No more than 2 anchors of each anchor type were placed in any 1 test environment of a single femur. Each anchor was tested in at least 5 different femurs. Ten specimens of each anchor were tested.[9,19] Two anchors were inserted directly perpendicular to the bone surface in different areas of the 2 test environments: the metaphyseal cortex and a cancellous trough. In this way 2 samples of each anchor were in each femur. The anchors were rotated through the different insertion positions in the test environments to average out bone thickness variations. Anchors were separated by at least 1 cm to prevent crack propagation between the insertion sites during testing. All anchors were inserted according to the manufacturers' instructions. Anchor insertion and pullout testing were conducted with the bones at room temperature to avoid any temperature-dependent variables in anchor component performance and to reduce variations in porcine femur response. The suture length gauge was not standardized. These tests were not carried out in an aqueous environment.

The porcine femurs containing the inserted suture anchors were positioned in a specially prepared holder that automatically aligned the sutures attached to the anchor directly under the actuator arm of a 3345 Instron mechanical testing machine (Instron, Canton, MA) with a 5,000-N maximum load cell (Fig 5). Consequently, the load applied was always parallel to the axis of anchor insertion. The holder was fixed to the load cell, and the sutures in the anchor were tied into a loop and passed over an "S" hook held in the upper hydraulic fixture. The upper arm was positioned so that there was no load on the device, and then, under program control, the upper fixture was raised until the device failed and the load dropped to baseline. A displacement rate of 12.5 mm/s was used to be consistent with previous articles in this series.[9]

The failure mode was observed and recorded for each anchor test. Anchor failure mode was defined to be "anchor pullout" whenever part or the entire anchor came completely out of the bone; "suture breakage" when the suture separated (broke) into 2 pieces; and "eyelet breakage" when the suture pulled out of the anchor intact. The latter mode requires the suture to cut through or break the portion of the anchor ("eyelet") securing it.

Statistical Analysis

A statistical analysis of these anchors should consider the different objectives of how the anchors are to be used. Glenoid anchors usually find greater purchase in younger denser bone and are not stressed by holding a tendon attached to a muscle. Cuff anchors risk

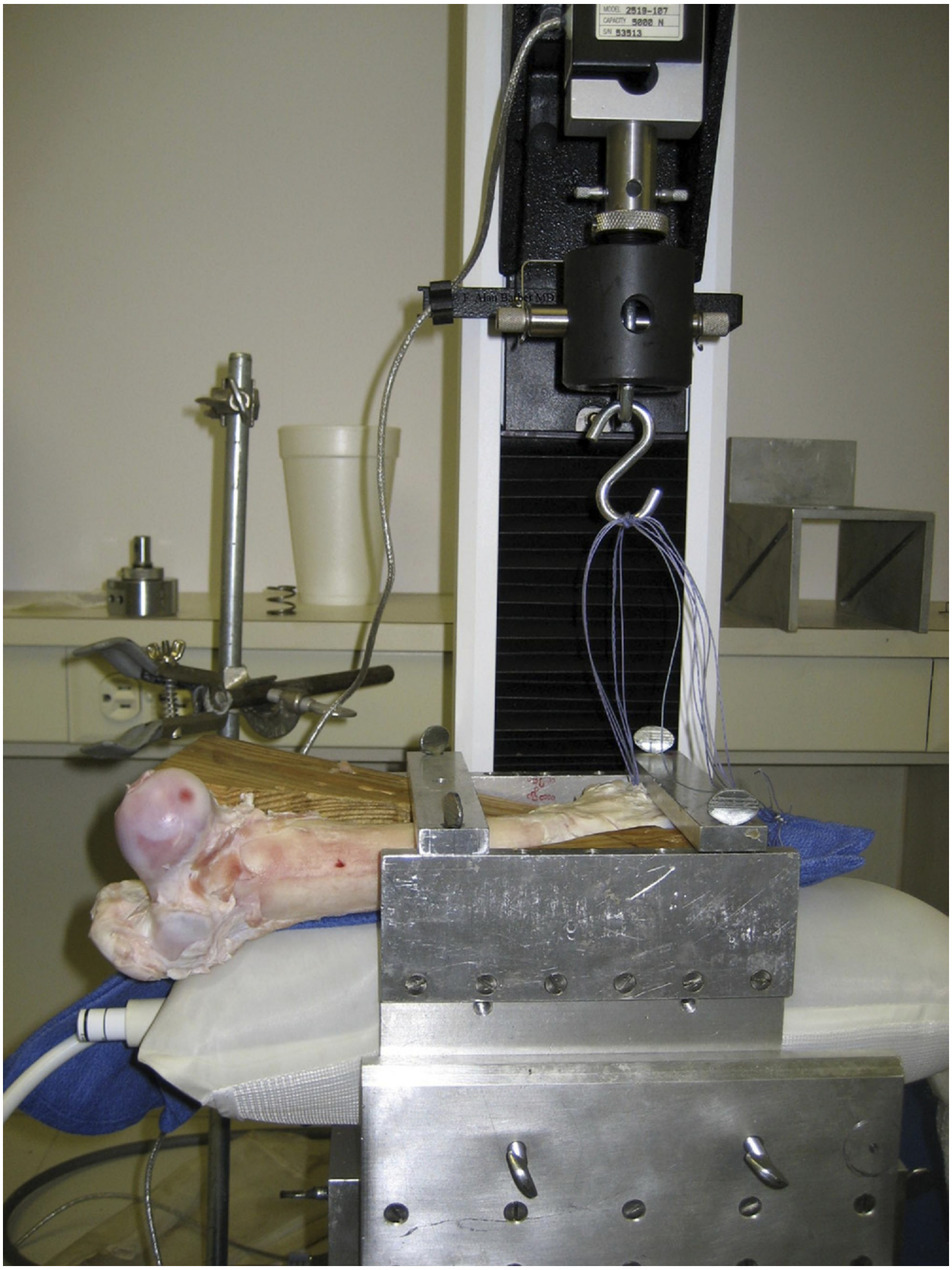

FIGURE 5. Mechanical testing machine setup used for anchor testing. © 2011 F. Alan Barber.

being cyclically loaded by muscle contraction (even in an arm supported by a pillow sling), are inserted into bone that is older and less dense, and often have 2 or 3 associated high-strength sutures instead of only 1. Statistical analysis was carried out with SAS software (version 9.1; SAS, Cary, NC) on a personal computer. Test data were analyzed for means and standard deviation, both for the whole data set and then for subsets by bone and failure mode. The general linear model for parametric analysis of variance was used to test for affects from bone and failure mode differences before the data were combined. Statistical significance was set at $P = .05$.

RESULTS

The anchor size, material, and number of sutures, as well as the defect an anchor makes in bone

TABLE 2. *Cortical Loads to Failure*

Anchor	Tests*	Mean Force (N)	SD (N)	Range (N)
Cuff anchors				
Doubleplay 5.0	10	279.2	23.3	253-325
Doubleplay 6.5	10	338.4	27.2	299-370
Opus SpeedScrew 5.5	10	356.9	19.2	330-382
Opus SpeedScrew 6.5	10	336.0	22.8	283-365
PEEK Intraline 5.5	10	262.8	23.9	207-295
PEEK Intraline 6.5	10	344.4	49.8	238-414
Zip 5.5	9	435.4	74.2	275-490
Zip 6.5	9	502.8	51.4	414-585
Paladin 5.0	8	500.0	62.4	405-569
Paladin 6.5	10	521.6	36.7	458-575
SuperRevo FT	11	496.3	70.5	360-595
CrossFT	7	569.5	139.1	375-828
Piton	10	379.0	34.9	319-406
ALLthread Ti 5.0	10	526.3	87.9	405-653
ALLthread Ti 6.5	9	653.7	94.9	473-830
ALLthread PEEK Triple 5.5	9	476.5	22.2	443-516
ALLthread PEEK Knotless 5.5	8	440.9	71.1	350-534
LactoScrew 5.5	8	402.9	70.6	242-462
Ti-Screw 5.0	9	457.4	55.4	371-547
Ti-Screw 6.5	9	443.2	23.9	420-485
Glenoid anchors				
Gryphon BR P	10	161.1	22.5	128-194
JuggerKnot 1.4	10	239.1	15.1	215-263

*Some of the anchors misfired, and the data were not collected.

(either the drill size or minor diameter of the screw anchor), are important and are recorded for each anchor in Table 1. These can then be compared with previous reports.[9,12,19-26]

Load to Failure

The anchors were tested in both metaphyseal cortical and metaphyseal cancellous bone. The mean failure loads for these anchor tests are reported in Tables 2 and 3. All of these anchors showed statistically equivalent failure loads in both cortical and cancellous bone sites except for the PEEK Zip 6.5 (greater in cortical [502 N] than cancellous [396 N]) ($P < .05$). Some anchors broke during insertion into the porcine bone, and consequently, fewer than 10 samples were available for testing in some instances.

Statistical analysis showed that failure force, while not dependent on location (cancellous or cortical bone) ($P = .58$), was dependent on the anchor type ($P < .001$). In addition, the larger threaded cuff anchors (e.g., SuperRevo FT, ALLthread 6.5, and ALLthread Ti 6.5) showed significantly greater failure loads than the smaller non-screw glenoid anchors (e.g., Gryphon BR P and JuggerKnot 1.4) ($P < .05$). The metal devices did not show higher failure loads than the PEEK devices.

Mode of Failure

The mode of failure is reported in Table 4.

DISCUSSION

Based on the data from the anchors available for testing, several observations can be made. The effective strength of these anchors is significant and generally reflects a trend toward higher-strength anchors, especially when rotator cuff applications are considered.[2,9,27] Braided polyester sutures have been replaced by high-strength UHMWPE-containing sutures. Nonmetallic anchor materials (e.g., PEEK and biodegradable polymers) are increasingly used in the newer designs. Knotless designs are finding more applications as "lateral row" cuff anchors rather than glenoid anchors.[28,29]

The anchor design has an impact on the load-to-failure strength, as well as the potential for complications.[30-32] Larger fully threaded screw designs showed high failure strengths. However, the larger version of

TABLE 3. *Cancellous Loads to Failure*

Anchor	Tests*	Mean Force (N)	SD (N)	Range (N)
Cuff anchors				
Doubleplay 5.0	9	262.7	30	218-314
Doubleplay 6.5	9	340.3	39.4	268-400
Opus SpeedScrew 5.5	10	356.3	15.4	330-382
Opus SpeedScrew 6.5	10	344.6	9.3	283-365
PEEK Intraline 5.5	10	273.6	36.2	217-341
PEEK Intraline 6.5	9	326.7	63.2	170-376
Zip 5.5	7	401.1	138.5	141-544
Zip 6.5	9	396.3	100.1	203-523
Paladin 5.0	12	427.3	107.5	257-658
Paladin 6.5	9	491.1	44.4	417-558
SuperRevo FT	10	483.4	65.0	419-630
CrossFT	10	546.8	160.1	252-714
Piton	10	365.3	81.1	219-465
ALLthread Ti 5.0	10	511.7	86.0	367-599
ALLthread Ti 6.5	11	611.7	106.9	436-832
ALLthread PEEK Triple 5.5	10	475.2	26.0	433-504
ALLthread PEEK Knotless 5.5	10	466.0	90.1	299-641
LactoScrew 5.5	8	435.0	27.2	381-464
Ti-Screw 5.0	10	420.0	63.4	296-491
Ti-Screw 6.5	10	448.4	27.1	410-497
Glenoid anchors				
Gryphon BR P	10	116.8	50.8	44-193
JuggerKnot 1.4	10	194.3	56.8	98-252

*Some of the anchors misfired, and the data were not collected.

a specific threaded screw anchor type did not provide a statistically greater failure load (i.e., 5.5 mm *v* 6.5 mm). The limiting factor has become the strength of the suture and the suture eyelet. Because the failure mode shown in these tests was seldom anchor pullout, these components have taken on a greater significance in anchor performance.

Anchor eyelet fixation has changed with a central core for the sutures becoming more common than the traditional eyelet. Even when anchors come with an eyelet, that eyelet is often not at the end in a hub but is located either in the main anchor body or as a distal crossbar. Dual cortical and cancellous thread designs and fully threaded designs for "cortical" fixation were increasingly observed.

In anchors with a distal crossbar serving as the anchor "eyelet," failure consistently occurred by the crossbar breaking. This means that the crossbar is weaker than the screw threads holding the anchor into the bone. This feature offers the safety advantage of further limiting the likelihood that such an anchor will be pulled from the bone.

The goal was to limit the failure mechanisms to either the anchor or the bone rather than the suture breakage. Failure mode is influenced by the anchor eyelet. Some of these anchors have conventional eyelets in proximal posts (Ti-Screw and LactoScrew), whereas others had eyelets in the main anchor body (Zip, PEEK Intraline, and Paladin). Still others have unconventional "eyelet" configurations such as crossbars at the distal end of the anchor body (Gryphon BR P, CrossFT, Opus SpeedScrew, and Doubleplay) or an internal independent eyelet fixation allowing the sutures to be contained entirely within the anchor body (ALLthread Ti, ALLthread PEEK, and SuperRevo FT).

Most biodegradable anchors (Doubleplay, Gryphon BR P, LactoScrew) showed eyelet failure as the predominant failure mode, although the Paladin anchor failed by suture breakage. Also notable was that except for the Gryphon BR P and JuggerKnot 1.4, all anchors were tested with 2 or 3 sutures.

Two sutures are now commonly loaded in a single anchor,[19] and when different sizes of the same anchor were tested, only 2 high-strength sutures were used. The high-strength No. 2 UHMWPE-containing sutures independently show load-to-failure ranges between 190 and 300 N compared with 92 N for No. 2 braided polyester.[19] This increased suture strength results in higher failure loads that reflect

TABLE 4. *Mode of Failure*

Anchor	Tests*	Anchor Pullout	Eyelet Breakage	Suture Breakage
Cuff anchors				
Doubleplay 5.0	19		17	2
Doubleplay 6.5	19		14	5
Opus SpeedScrew 5.5	20		20	
Opus SpeedScrew 6.5	20		20	
PEEK Intraline 5.5	20		18	2
PEEK Intraline 6.5	19	1	16	2
Zip 5.5	16	8	2	6
Zip 6.5	18	7		11
Paladin 5.0	20	5	4	11
Paladin 6.5	20	4	2	13
SuperRevo FT	21	2		19
CrossFT	17	8	1	8
Piton	20	1	4	15
ALLthread Ti 5.0	19	5		14
ALLthread Ti 6.5	20	1	10	9
ALLthread PEEK Triple 5.5	19	1	18	
ALLthread PEEK Knotless 5.5	18		1	17
LactoScrew 5.5	16	1	15	
Ti-Screw 5.0	20	4	13	3
Ti-Screw 6.5	19	1	9	9
Glenoid anchors				
Gryphon BR P	20	8	12	
JuggerKnot 1.4	20	9		11

*Some of the anchors misfired, and the data were not collected.

the higher suture breaking strength. High suture strength then places more stress on the anchor eyelet, and anchor eyelet design strength becomes more critical to the overall anchor performance than bone-holding strength.

The materials used in these anchors include PEEK, various biodegradable copolymers (self-reinforced PL[96%]D[4%]LA, 30% β-TCP/70% poly levo-co-glycolic acid, 30% β-TCP/70% PLLA, and 85% PLLA/15% polyglycolic acid), and titanium. PEEK is a non-biodegradable, very chemically resistant crystalline thermoplastic. As a suture anchor, it is nonabsorbable, strong, and radiolucent and may be drilled out during revision surgery. However, the particles generated during such drilling must be completely removed to avoid abrasive damage to the joint.

Whereas knotless anchors were initially introduced as glenoid anchors and were advanced as a way to avoid the challenge of arthroscopic knot tying, current knotless anchors are designed to support a dual- or lateral-row rotator cuff repair. Securing sutures already fixed by a more proximal anchor creates challenges that are addressed by these new designs. These anchor innovations target the ultimate goal of improving clinical results by improving the incidence of rotator cuff healing.[20,33]

Another observation is the proportion of new anchors tested that were designed for the rotator cuff rather than the glenoid. Only 2 of these anchors are specifically glenoid anchors (Gryphon BR P and JuggerKnot). These glenoid designs are smaller and, as a consequence, have lower failure loads than the cuff anchors. Cuff lateral-row “knotless” designs are represented by the Opus SpeedScrew, Piton, and ALLthread PEEK knotless anchors. Failure mode for the knotless anchors was principally suture breakage and not anchor pullout.

It is notable that as many of the recently released anchors were manufactured from PEEK as from a biodegradable material, which is different from previous reports. In addition, the development trend is clearly focused at this point on larger anchors intended for use with rotator cuff repair rather than smaller anchors with glenoid applications. The newer knotless anchors are lateral-row rotator cuff designs rather than glenoid anchors.

Study limitations include the bench-test nature of this in vitro study, which was performed at room temperature in a dry (non-arthroscopic) environment using pig bones and a small number of anchors. The application of a load in line with the anchor insertion angle does not replicate the in vivo anchor loading and represents a worst-case situation. This test does not have direct application to the clinical setting and is a biomechanical study with no cyclical testing component. All manufacturers did not participate in this study. Clinical outcomes cannot be drawn from these load-to-failure data because despite high load-to-failure strength, it should be emphasized that the weakest link in any rotator cuff tendon–suture anchor construct is the tendon-suture interface.[34] The consistent use of high-strength sutures makes the disparity between the tissue and suture even greater.

CONCLUSIONS

Failure load was not dependent on anchor location (cancellous or cortical bone) ($P = .58$) but was dependent on the anchor type (cuff anchor or glenoid anchor) ($P < .001$). Whereas larger fully threaded screw anchors designed for rotator cuff repair showed higher failure strengths than smaller non-screw anchors designed for glenoid repairs ($P < .05$), the larger version of a screw anchor for a cuff repair did not provide a statistically greater failure load than the smaller screw anchor.

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